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Pilot Plant Study on the Use of Chlorine Dioxide and Granular Activated Carbon

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Chlorine dioxide is shown to be an effective disinfectant and its use allowed a 30–40% reduction in trihalomethane precursors in this pilot plant study in Evansville, Ind. Granular activated carbon removed up to 80% of the remaining precursors at the beginning of a test run when the influent concentration was high (120 μg/L) with no removals at exhaustion after 30 days of use. Performance curves for total organic carbon removal were constructed for virgin and regenerated granular activated carbon; both showed an initial average removal of about 75%, and, after total organic carbon-exhaustion of about 60 days, the rate dropped to 23%. Chlorine dioxide did not produce any organic byproducts other than those noted with chlorine disinfection.

PURSUANT TO PROVISIONS of the Safe Drinking Water Act (Public Law 93-523), extramural research within the U.S. Environmental Protection Agency was designed to satisfy a basic need within the water treatment and supply industry: reduction or prevention of organic compounds in drinking water. As a result of this research objective, an experimental study was initiated in Evansville, Ind. to investigate the use of chlorine dioxide disinfection and posttreatment adsorption by granular activated carbon (GAC). This effort was designed to evaluate a treatment scheme that could drastically reduce or possibly prevent the production of trihalomethanes in the disinfection process in addition to removing other

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organic compounds by adsorption on GAC. Specific objectives established for this project included:

- Development of a water treatment process using chlorine dioxide as a disinfectant to evaluate the resultant production of trihalomethanes and specific organics as compared to chlorine disinfection.
- Determining if any organic byproducts are formed when using chlorine dioxide as a disinfectant as contrasted to chlorine disinfection.
- Determining the effectiveness of virgin and subsequent reactivated GAC for removal of organic compounds present in the source water, as well as any formed after chlorine dioxide disinfection.

Operation

Full-Scale Treatment Plant Description. One portion of the Evansville Water Treatment Plant was used as a control in this project. The total plant was constructed in a "Y" configuration consisting of two separate treatment schemes with each having a capacity to treat approximately 113.6 million L/day (30 million gallons/day). The South portion of the plant was used as the control, mainly because construction activity was underway at the North plant.

Figure 1 is a flow diagram of the South portion of the full-scale plant. The raw water intakes are located on the Ohio River about 804.5 m (one-half mile) upstream from the city of Evansville. The South plant consists of two primary settling basins, two secondary settling basins, and eight rapid sand filters. Each primary settling basin is 39.6 m (130 ft) in diameter and 5.3 m (17.5 ft) deep with a capacity of approximately 6.8 megaliters (1.8 million gallons). The secondary settling basins are each 27.4 m (90 ft) in diameter with a 4.6 m (15-ft) sidewall depth and a capacity of 2.7 megaliters (0.725 million gallons). Settled water enters the filter building through concrete-lined steel pipes to the sand filters consisting of layers of gravel, sand, and anthracite (mixed media filtration).

Chlorine and alum were added to the raw water with average concentrations of 6 and 28 mg/L, respectively. These concentrations varied, depending on the demand and turbidity. Chlorine dosages were predicated on maintaining a free chlorine residual of 1.5–2.0 mg/L after sand filtration. If make-up chlorine was needed, it was added before the water passed into a common clearwell. Approximately 12 mg/L of lime was added after primary settling for pH control.

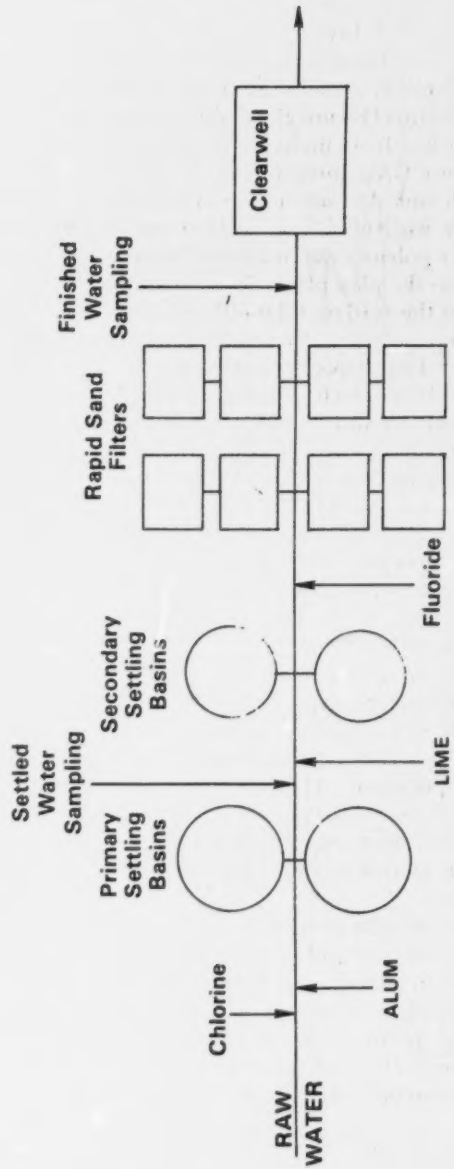

Figure 1. Flow diagram of Evansville, IN full-scale South plant.

Pilot Plant Description. As a means for studying treatment and operational options at Evansville without disrupting the normal water supply procedure, a 378.5 L/min (100 gallons/min) Neptune Micro-Floc[1] unit was purchased and housed on-site. This unit, or pilot plant, consisted of a rapid mix chamber, a mechanical flocculator, and a settling tube chamber for clarification (Figure 2). Clarified water then passed through a mixed media filter bed to an underdrain system where it was pumped to two parallel pressure GAC contactors or directly to a combination clearwell and backwash tank. Average alum and polymer dosages of 12 and 0.8 mg/L, respectively, were used for turbidity removal. Although not used in the full-size plant, a polymer was necessary because of the short detention time of the water in the pilot plant. For pH control to 8, about 6 mg/L of lime was added to the settling tube effluent. Types of disinfectants and dosages varied depending on the mode of operation. This will be explained in the Pilot Plant Operation section.

Each of two GAC contactors was constructed with a straight column height of 2.4 m (8.0 ft) and an inside diameter of 0.97 m (38 in.). An average carbon bed depth of 2.0 m (6.5 ft) was used to allow for expansion of the GAC during backwash. A hydraulic loading of 3.5 Lps/m^2 (5.1 gallons/min /sq ft) was used to provide a total empty bed contact time of 9.6 min for each contactor. Sample taps consisting of 0.6-cm (1/4-in.) diameter stainless steel pipe were provided at 30-cm (1-ft) increments. A 10-cm (4-in.) diameter opening located just above the Neva Clog underdrain was used for carbon eduction. A similar 10-cm (4-in.) opening was provided at the top of each contactor for carbon replenishment.

For this study, conventional materials normally used in utility construction were also used in the pilot plant. This included carbon steel with an epoxy paint, which was nontoxic and chemical resistant, applied to the inside of the carbon contactors and clearwell to control corrosion.

Pilot Plant Operation. The project at Evansville was designed to include four distinct sequential phases: training, shakedown, optimization, and operating phase. The training and shakedown phases were necessary to assure efficient operation of the pilot plant and to establish reliable sampling techniques.

The optimization phase consisted of a control study and three different experimental modes of operation. For the control study, the pilot plant was operated in a similar mode to the full-scale plant, namely pre- and postchlorine disinfection, with comparisons lasting for 2 weeks. Comparison of the performance of the three experimental modes of operation to the full-scale plant was 3 weeks duration each and consisted of the modes as shown in Table I. These short-term modes were evaluated

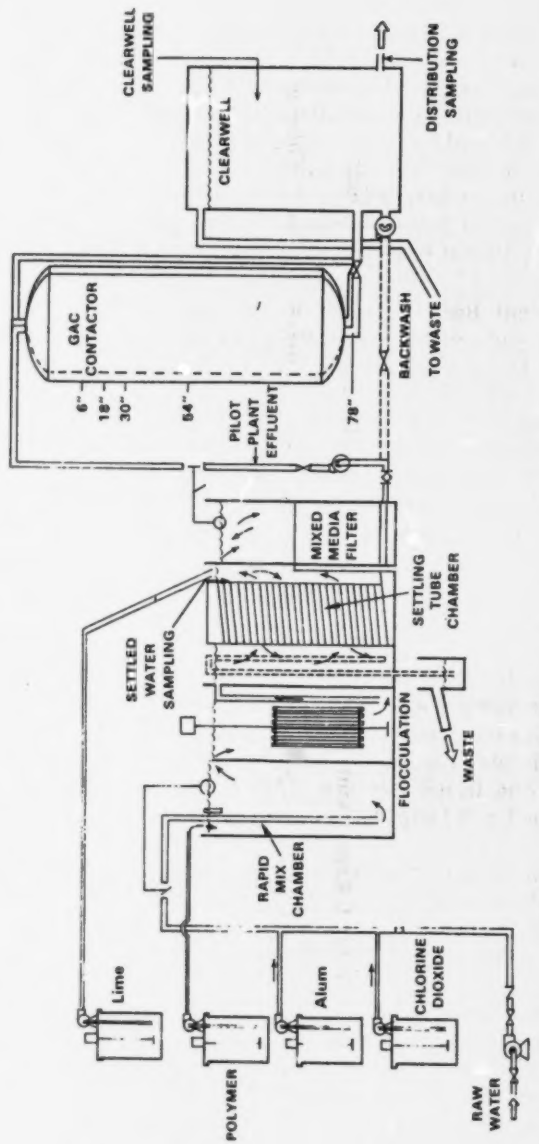

Figure 2. Schematic diagram of Evansville, IN pilot plant.

Table 1. Experimental Modes of Operation for Pilot Plant at Evansville, Ind.

Run	Chlorine	Chlorine dioxide	Alum	Polymer	Mix	Settle	Lime	Filter	Carbon	Chlorine	Chlorine dioxide
1			X	X	X	X	X	X	X	X	X
2	X		X	X	X	X	X	X	X		
3			X	X	X	X	X	X	X	X	
4		X	X	X	X	X	X	X	X		X

so that an operational mode could be selected for long-term evaluation during the operating phase.

A total of four runs was completed in the operating phase with each consisting of continuous operation for approximately 3 months. The length of these runs was determined by evaluating the total organic carbon (TOC) and the instantaneous trihalomethanes (InstTHM) for GAC exhaustion. Disinfection in the pilot plant was provided by chlorine dioxide generated from the reaction of sodium hypochlorite (NaOCl) and sodium chlorite ($NaClO_2$) after the pH had been adjusted to 3.0 ± 0.5 with hydrochloric acid. Chlorine dioxide dosages applied to the raw water averaged about 1.5 mg/L to establish a residual of 0.3–0.5 mg/L after mixed media filtration.

For all runs, the performance of the pilot plant through GAC treatment was compared with the performance of the full-scale plant under normal operation. The first run consisted of virgin GAC placed in the two parallel contactors to establish a baseline for subsequent regenerations (reactivations). This parallel comparison provided the opportunity to evaluate the reproducibility of results between the two contactors and to judge minor from major differences when performing evaluations between virgin and regenerated GAC in subsequent comparisons. One contactor (designated T4P) contained 599 kg (1,231 lb) of GAC, while the other one (T5P) contained 567 kg (1,249 lb).

GAC Handling and Regeneration

ICI's Hydrodarco 10 × 30 lignite-based GAC was used. Each contactor, when filled to the designated depth, contained between 545 and 590 kg (1,200 and 1,300 lb) of GAC. The GAC was inducted and educted from the contactors by a water jet that discharged at a rate of 129–140 L/min (34–37 gallons/min). After GAC was introduced into the contactors, it was backwashed for about 2.5 h at 303 L/min (80 gallons/min) to remove the fines.

The GAC to be regenerated was educted into epoxy-coated 208-L (55-gallon) drums containing well screens. The well screens allowed for dewatering of the GAC after eduction and regeneration. On all but one run, the GAC in the drums was shipped to Passaic Valley, N.J. for regeneration.

A 45.4-kg (100-lb) per hour Shirco infrared furnace was used for regeneration of the spent GAC. The GAC was unloaded directly from the 208-L (55-gallon) drums into a small hopper at the base of the carbon-feed screw conveyor. This GAC was dewatered by the conveyor to approximately 50% moisture and fed into the furnace where it dropped onto a woven wire conveyor belt and was leveled into a layer approxi-

mately 1.9-cm (3/4-in.) thick. The conveyor belt moved the GAC underneath the infrared heating elements that provided the energy necessary to dry the carbon, drive off adsorbed compounds, and restore the pore structure. Process temperatures were controlled in zones and typically ranged from 1200°F in the drying zone to about 1700°F in the reactivation zone. Residence time of the GAC in the furnace was 20–30 min. Regenerated GAC was quenched and transported back to the drums for shipment to Evansville.

Sampling and Analysis

All sampling was done on a time-sequence basis, so that the same portion of raw water entering both plants was sampled at specified locations. Analysis performed during the extent of the project consisted of quantification of 14 volatile and eight solvent extractable organic compounds as shown in Table II.

The volatile organics were determined by purge and trap procedures using a Tenax trap for adsorption/desorption and detection by electrolytic conductivity detectors. Extractable organics were concentrated for analysis using 15% methylene chloride in hexane after acidification of a 2-L aliquot. After concentration, the hexane was methylated using diazomethane in ethyl ether. The sample was then further concentrated to 5 mL and analyzed by electron-capture GC.

In addition, qualitative (detected/nondetected) determinations were performed by MS scans for 32 additional volatiles and 54 extractable organics. Data were also collected on nine inorganic metals (maximum

Table II. Quantifiable Organic Compounds of Interest

Volatile Organic Compounds

Acrolein	Dibromochloromethane
Acrylonitrile	1,2-Dichloroethane
Benzene	1,1-Dichloroethylene
Bromodichloromethane	Ethylbenzene
Bromoform	Tetrachloroethylene
Carbon tetrachloride	1,1,1-Trichloroethane
Chloroform	Trichloroethylene

Extractable Organic Compounds

Bis(2-ethylhexyl) phthalate	1,4-Dichlorobenzene
Butyl benzyl phthalate	Hexachlorobenzene
Di-*N*-butyl phthalate	Hexachloroethane
1,2-Dichlorobenzene	1,2,4-Trichlorobenzene

contaminant levels), TOC, and other parameters such as turbidity, standard plate count, coliforms, and the disinfectants (chlorine and chlorine dioxide).

Control Study

The performance of the pilot plant without the carbon contactors in operation was compared to the full-scale plant to determine if the full-scale plant could be used as a control for subsequent experimentation with the pilot plant. Chlorine disinfection was used in both plants for a 2-week extensive evaluation. As shown in Table III, the average concentrations of the two plant effluents were comparable.

This close comparison occurred even though the two treatment systems are dissimilar. The main difference between these treatment systems is that the pilot plant employs a much shorter detention time (approximately 37 min) than the full-scale plant (approximately 5 h) with comparable flow differences such that during this study the South portion of the full-scale plant averaged 71.2 million L/day (18.8 million gallons/day) and the pilot plant averaged 303 L/min (80 gallons/min). Because of the contact time difference, an anionic high molecular weight flocculant was used in the pilot plant to accomplish acceptable turbidity removals.

The only major discrepancy between the pilot plant and the full-scale plant effluents was the carbon tetrachloride. The high concentration of carbon tetrachloride in the full-scale plant effluent was suspected of coming from contaminated chlorine gas. This supposition evolved because no carbon tetrachloride was detected in the pilot plant effluent. The two systems were chlorinated differently with calcium hypochlorite being used for chlorine disinfection in the pilot plant and chlorine gas in the full-scale plant.

This problem was eliminated after some excellent detective work by the utility. They were able to trace down the source of contamination and by making the supplier aware that they had the capability and would monitor for carbon tetrachloride, the supplier "cleaned-up" his operation and no further contaminated chlorine gas was received.

Pilot Plant Study

After the optimization phase (discussed previously) was completed, a mode of operation consisting of chlorine dioxide disinfection of the raw water and after GAC treatment was adopted. This mode of operation was used in all four runs in the operating phase.

Virgin GAC Comparisons. The performance of the two parallel

Table III. Performance Comparison of Pilot and Full-Scale Plants

	Instantaneous Samples		
Parameter	*Raw Water*	*Pilot Plant Effluent*	*Full-Scale Plant Effluent*
Total InstTHM (μg/L)	1.9	33.6	36.9
TOC (mg/L)	2.9	2.1	1.8
Carbon tetrachloride (μg/L)	< 0.1	< 0.1	32.0
1,2-Dichloroethane (μg/L)	< 0.1	< 0.1	< 0.1
Tetrachloroethylene (μg/L)	< 0.1	< 0.1	< 0.1
Turbidity (NTU)	77.0	0.33	0.18
Chlorine (mg/L)	0	1.5	1.9
Median pH	7.5	7.5	7.4
Temperature (°C)	13.3	—	14.6
Coliforms (number/100 mL)	13,000	0	0
Total plate count (number/1 mL)	1,400	2	0

contactors was compared while using identical flows to each contactor that contained approximately the same amount of virgin GAC. The two contactors performed similarly. With an influent TOC concentration of 2–3 mg/L, both contactors were removing about 75% at the beginning of the run. By Day 60, only about 30% of the TOC was being removed, although this removal remained fairly constant, even with a fluctuating influent (Figure 3).

In comparing the performance of the virgin GAC, InstTHMs also were evaluated. For those not familiar with THM terminology, a complete description has been prepared by Stevens and Symons (*1*). The InstTHM was formed by unreacted chlorine used in the production of chlorine dioxide. Even at the low concentrations shown in Figure 4 (< 5 μg/L) applied to the GAC, equilibrium occurred in about 60 days.

From this observation, it appears that GAC performance for InstTHM cannot be assumed to allow for longer operation before exhaustion if the applied concentrations are low. Because the concentrations are low, however, even at exhaustion, the GAC effluent was below the promulgated standard (0.1 mg/L). This same phenomenon occurred for two of three other runs (Figures 5 and 6). For these two runs, the effluent concentration from the GAC contactors exceeded the applied concen-

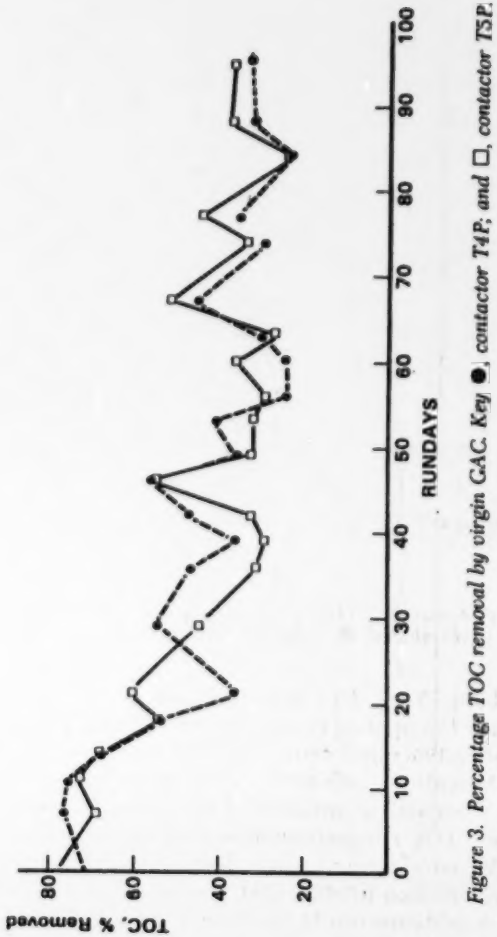

Figure 3. Percentage TOC removal by virgin GAC. Key: ●, contactor T4P; and □, contactor T5P.

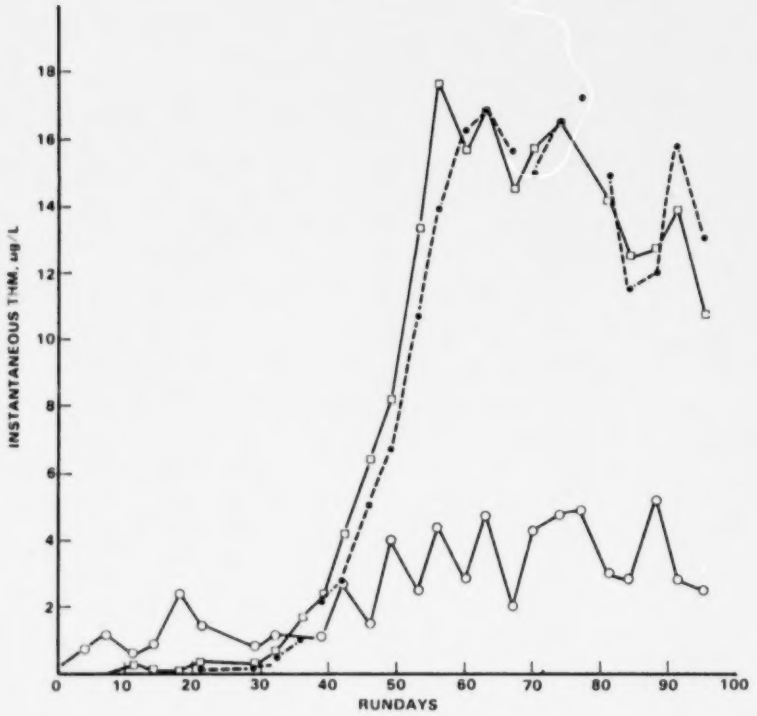

Figure 4. Instantaneous THM performance through virgin GAC. Key: ○, GAC influent; ●, contactor T4P; and □, contactor T5P.

tration in about 15–20 days. Other related studies have shown similar observations at low applied concentrations (*2*).

GAC exhaustion was determined by the equilibrium of adsorbed TOC and InstTHM with the influent concentration. By evaluating these two parameters, the length of operation of the contactors was determined. As already shown, TOC concentrations were at steady-state in about 60 days and InstTHM concentrations reached equilibrium in about the same time period. By comparison to other GAC studies (*2, 3*), the concentration of InstTHM at equilibrium was higher than anticipated based on the applied concentration to the GAC. At this time, no explanation can be given for this occurrence.

Although the GAC was exhausted in about 60 days, each run was allowed to continue for approximately 90 days. This extension was needed

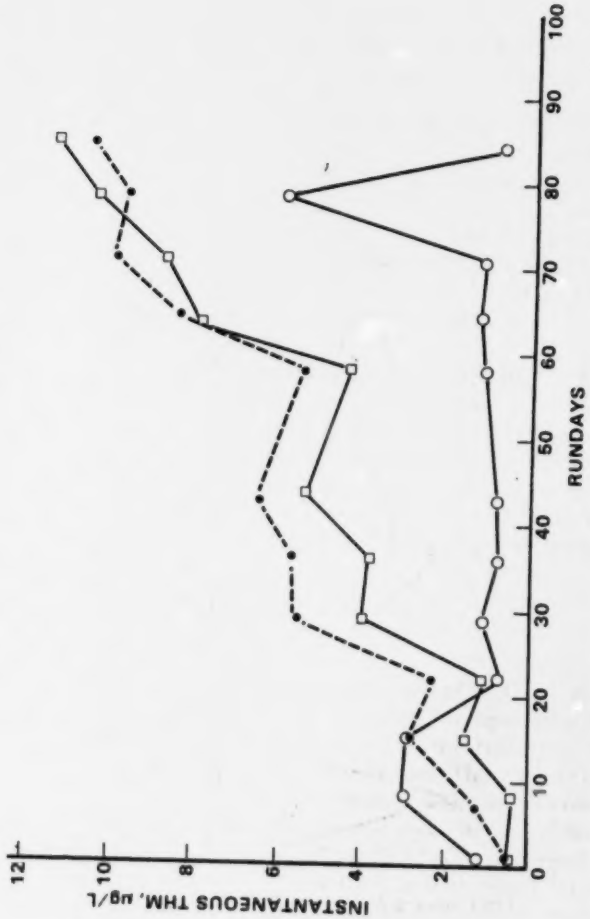

Figure 5. Comparison of instantaneous THM levels from virgin and once regenerated GAC. Key: ○, GAC influent; ●, virgin GAC; and □, regenerated GAC.

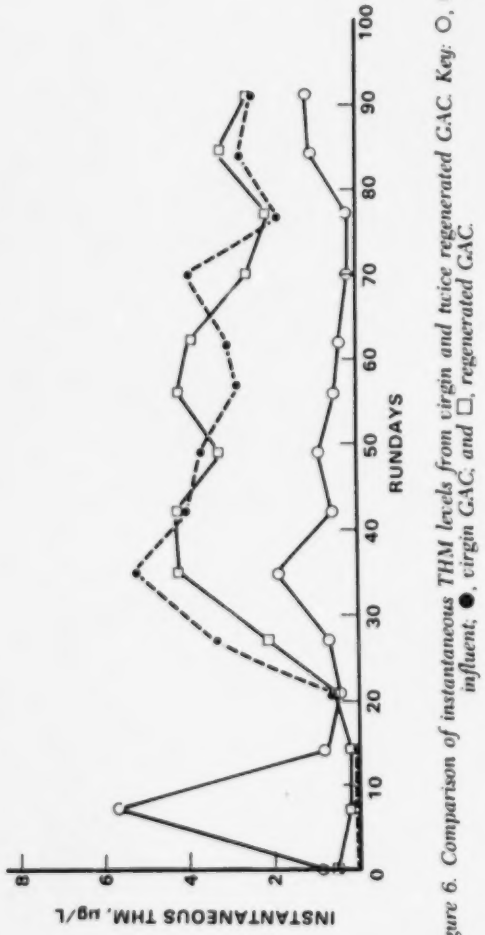

Figure 6. Comparison of instantaneous THM levels from virgin and twice regenerated GAC. Key: ○, GAC influent; ●, virgin GAC; and □, regenerated GAC.

to collect enough data to be sure that the parameter concentrations had actually reached steady-state or equilibrium conditions.

Virgin Compared to Regenerated GAC. The original spent virgin GAC was regenerated subsequently three times. Except for the first regeneration, make-up virgin GAC was required to replenish losses resulting from handling and regeneration. For each run, fresh virgin GAC was added to contactor T4P and its performance was compared to the subsequent regenerated GAC in contactor T5P. Depending on the run, the amount of GAC in these contactors ranged from 499 to 590 kg (from 1,100 to 1,300 lbs).

For all runs when compared to the virgin GAC, the TOC concentration of the subsequent regenerated GAC was practically identical except for the last run where the thrice-regenerated GAC seemed to perform somewhat more effectively (Figures 7–9). This trend was opposite for the terminal THM as shown in Figures 10–12. But in both cases indications were that regeneration had restored the GAC to a state where its performance was similar to the virgin GAC. It should be noted that the terminal THM is essentially the same as the formation potential because of the low instantaneous values.

By evaluating the GAC properties as shown in Table IV for each run, an indication for the slightly improved performance of the regenerated GAC for TOC might be attributed to a change in pore structure. When looking at the iodine number and molasses number, for all runs, a trend has developed whereby the iodine number increased from 617 to 650 mg/g and the molasses number decreased from 357 to 310. This type of trend generally occurs with the subsequent regenerations and does indicate some pore structure change.

Discussion

Samples of raw water, pilot plant effluent before GAC, and full-scale plant effluent were stored for 3 days at ambient temperature and a pH of 8.0 with a free chlorine residual to simulate the residence time at the farthest point in Evansville's distribution system. This gave an opportunity to evaluate a system using pre- and postchlorination as compared to a similar one using pre-chlorine dioxide and post-chlorine disinfection.

The pH in the pilot plant ranged from 6.6 to 8.9. In the full-scale plant it varied from 7.0 to 8.5. Lime was utilized in both plants for pH control. The temperature of the water in both plants varied depending on the season with an average range of 12.6–22.1°C.

As shown in Figure 13, the use of pre-chlorine dioxide disinfection allows about 30–40% more of the THM precursors to be removed by coagulation/settling than with prechlorination, thereby reducing the

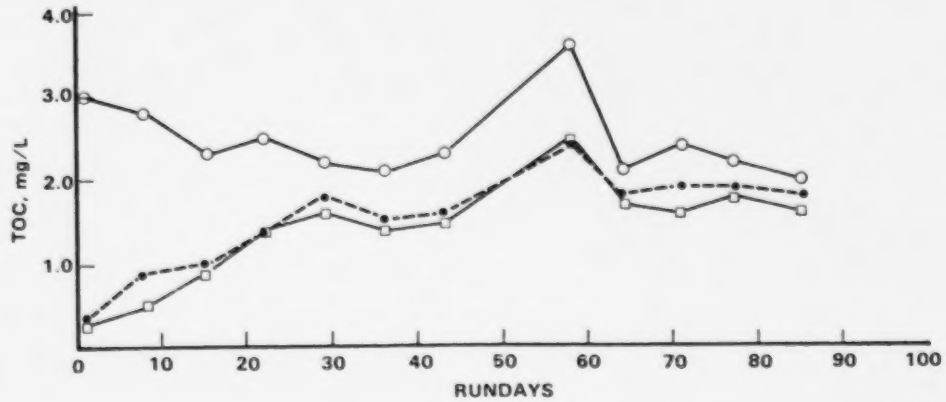

Figure 7. Comparison of TOC levels from virgin and once regenerated GAC. Key: ○, GAC influent; ●, virgin GAC; and □, regenerated GAC.

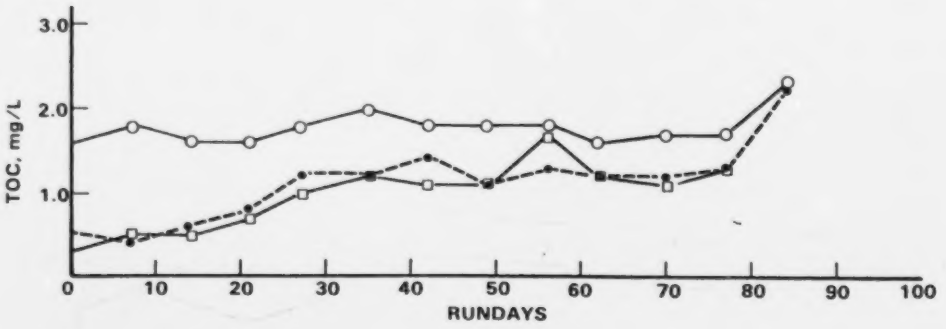

Figure 8. Comparison of TOC levels from virgin and twice regenerated GAC. Key: ○, GAC influent; ●, virgin GAC; and □, regenerated GAC.

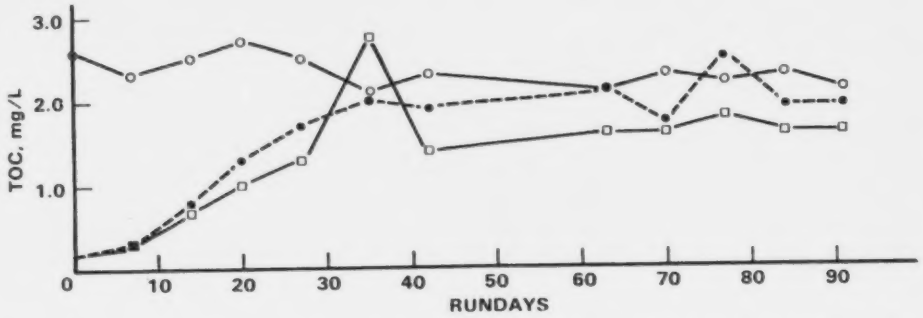

Figure 9. Comparison of TOC levels from virgin and thrice regenerated GAC. Key: ○, GAC influent; ●, virgin GAC; and □, regenerated GAC.

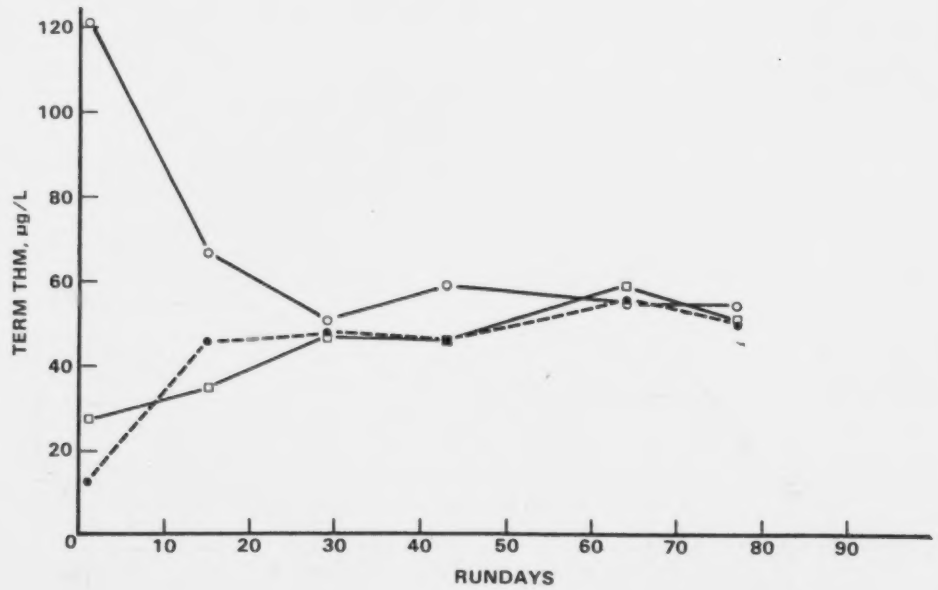

Figure 10. Comparison of terminal THM levels from virgin and once regenerated GAC. Key: ○, GAC influent; ●, virgin GAC; and □, regenerated GAC.

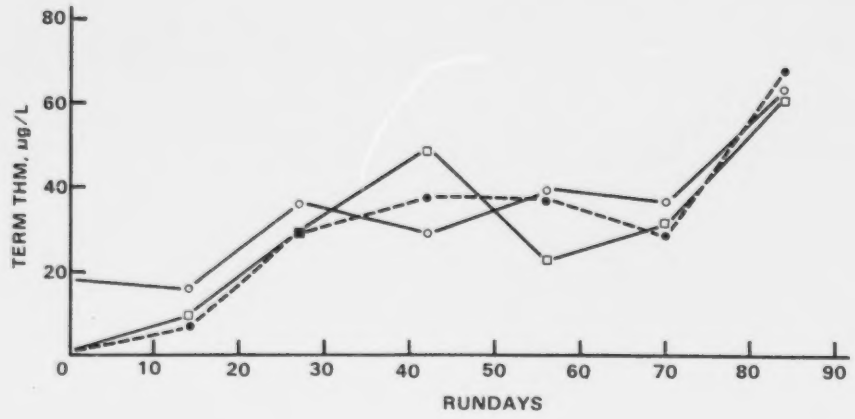

Figure 11. Comparison of terminal THM levels from virgin and twice regenerated GAC. Key: ○, GAC influent; ●, virgin GAC; and □, regenerated GAC.

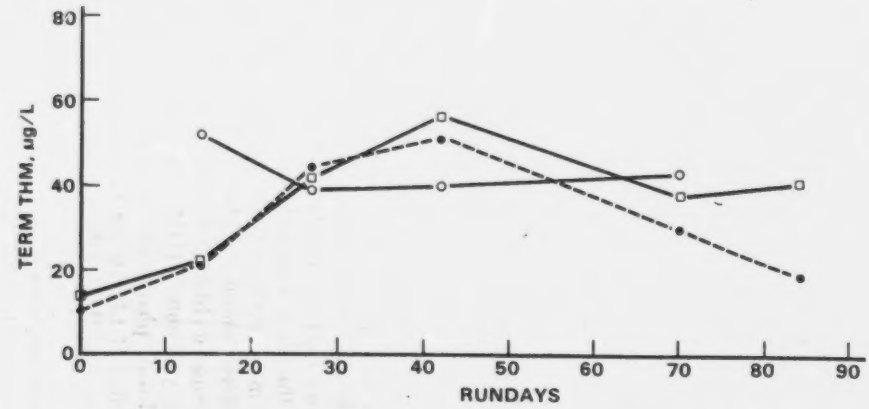

Figure 12. Comparison of terminal THM levels from virgin and thrice regenerated GAC. Key: ○, GAC influent; ●, virgin GAC; and □, regenerated GAC.

Table IV. Properties for Virgin and Subsequent Regenerated GAC

GAC Properties	*Virgin*	*Run 1*	*Run 2*	*Run 3*
Surface area (m^2/g)	597	S-UNK	S-636[a]	S-656[a]
		R-675	R-644	R-668
Apparent density (g/cc)	0.427	R-0.554	S-0.434	S-0.443
		R-0.447	R-0.403	R-0.440
Iodine number (mg/g)	617	S-470	S-432	S-467
		R-638	R-596	R-650
Molasses number	357	S-345	S-255	S-250
		R-365	R-324	R-310
Ash content (%)	15.3	S-13.8	S-14.8	S-16.5
		R-13.9	R-15.7	R-17.9
Effective size (mm)	0.80	S-0.74	S-0.70	S-0.70
		R-0.75	R-0.74	R-0.74

Note: S = spent and R = regenerated (before any make-up GAC added).
[a]Sample calcined before analysis.

amount of THM formed during posttreatment chlorination. Because the stored samples for both plants were in the presence of a free chlorine residual for exactly 3 days, the full-scale plant effluent was actually in contact with a free chlorine residual for 5 h longer because of the detention time in the plant. This additional time, however, had no effect on the data shown in Figure 13 as substantiated by the optimization phase control study for stored samples as shown in Table V.

Therefore, the use of chlorine dioxide as a predisinfectant in the pilot plant substantially prevented THM from reaching the concentration present in the full-scale plant under normal operations using chlorine to obtain a free residual of 1.5–2.0 mg/L. No difference was noted in the TOC concentration regardless of the type of predisinfection used (Figure 14).

Chlorine dioxide has been shown to reduce the THM concentration, but what other potentially harmful chemicals are formed by its use? A total of 108 different organic chemicals was evaluated by conventional packed column, GC–MS confirmation and no byproducts attributable to chlorine dioxide were identified. Also, no organics were detected from the use of the epoxy paint.

The fate of chlorine dioxide and one of its inorganic species (chlorite) varied during treatment. In generating chlorine dioxide, a stoichiometric

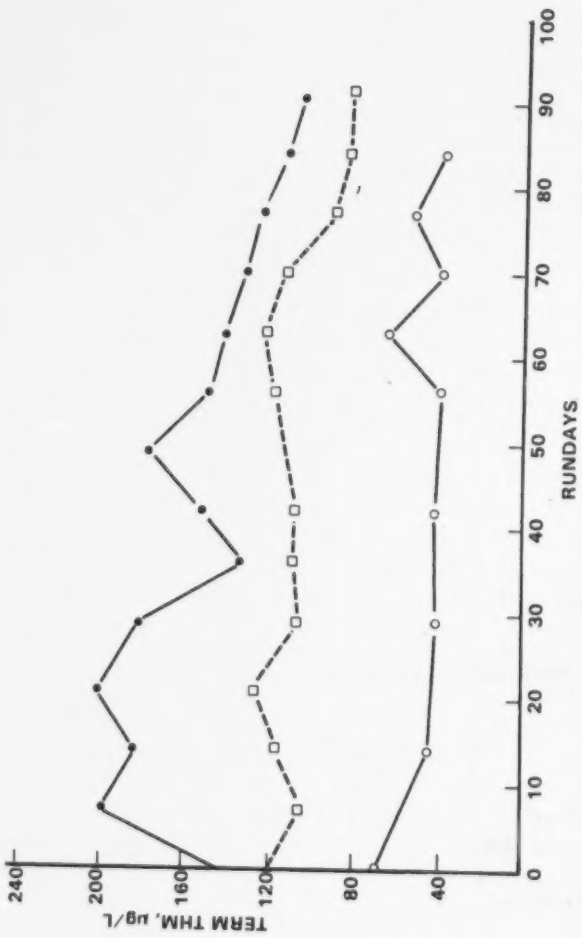

Figure 13. Comparison of average terminal THM levels in full-scale and pilot plant effluent. Key: ●, raw water; ○, pilot plant effluent; and □, full-scale effluent.

reaction was not possible, thereby introducing an average of about 0.8 mg/L chlorite, when an average dosage of 1.5 mg/L chlorine dioxide was applied to the raw water. After filtration, the concentration of chlorine dioxide and chlorite was in the range of 0.3–0.5 and 1.5–2.0 mg/L, respectively, depending on the raw water dosage. The chlorine dioxide was quickly removed by GAC, while the chlorite concentration was reduced to about 0.5 mg/L after a GAC empty bed contact time of 9.6 min.

Bacteriological samples were taken for in-plant analysis of the standard plate count (SPC) and total coliform. Raw water concentrations for SPC averaged about 4,000/mL, with counts up to 40,000/mL. Application of chlorine dioxide reduced this number to about 50/mL after filtration (GAC influent). These average levels increased through the GAC contactors to about 500/mL and 300/mL for the virgin and subsequent regenerated GAC, respectively.

Total coliforms on the other hand averaged about 11,000/100 mL in the raw water and were reduced to about 1/100 mL through filtration with chlorine dioxide disinfection. About 1/100 mL was detected in both the virgin and subsequent regenerated GAC effluents. After post-GAC disinfection with chlorine dioxide, an average SPC of 4/mL and no total coliforms were detected.

Filtration without a predisinfectant had some effect on the bacteriological quality of the water. During this operational mode, a removal of 84% for the SPC (from 290 to 45/mL) and 30% for the total coliforms (from 5,400 to 3,800/100 mL) was noted. This compares to 99% for the SPC and 100% for the total coliforms using the average values presented when chlorine dioxide was used as a predisinfectant.

Although, in several instances, average concentrations for this study

Table V. Performance Comparison of Pilot and Full-Scale Plants
3-Day Stored Samples

Parameter	*Raw Water*	*Pilot-Plant Effluent*	*Full-Scale Plant Effluent*
TermTHM (μg/L)	127.4	76.3	73.3
Carbon tetrachloride (μg/L)	< 0.1	< 0.1	31.1
1,2-Dichloroethane (μg/L)	< 0.1	< 0.1	< 0.1
Tetrachloroethylene (μg/L)	< 0.1	< 0.1	< 0.1
Chlorine (mg/L)	2.8	1.7	2.4
Median pH	8.0	8.0	8.0
Temperature (°C)	13.5	13.6	13.8

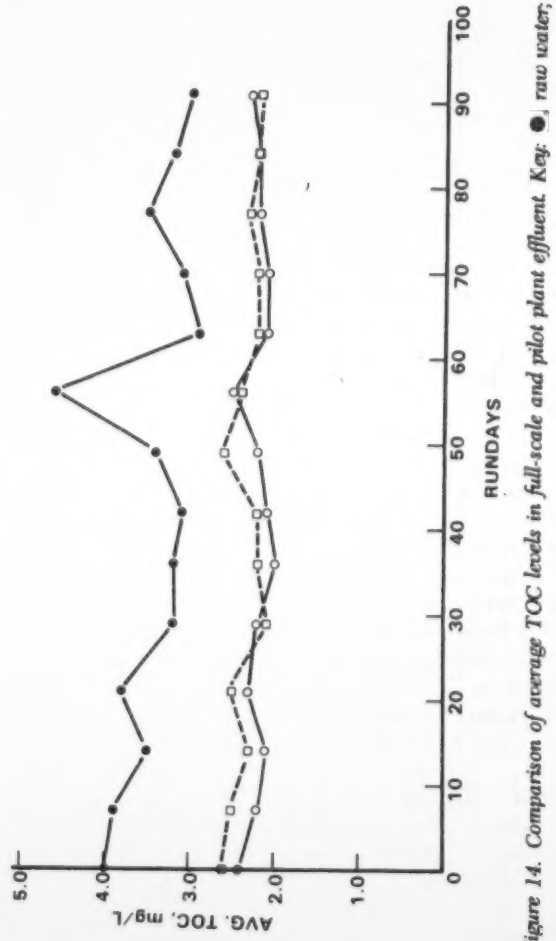

Figure 14. Comparison of average TOC levels in full-scale and pilot plant effluent. Key: ●, raw water; ○, pilot plant effluent and □, full-scale effluent.

have been presented and it appears that the subsequent regenerated GAC performs as well as virgin GAC, a more in depth evaluation is forthcoming. As part of this evaluation, the morphological changes occurring in the GAC will be compared to its performance. On the surface, as with the performance data, GAC properties indicate that the regenerated GAC was essentially restored to virgin state as shown in Table IV. GAC losses incurred during regeneration were about 5% with overall system losses (eduction, handling, transport, and regeneration) averaging about 8%.

Summary

During this study, chlorine dioxide was shown to be an effective disinfectant and its use allowed a 30–40% reduction in THM precursors. Up to 80% of the remaining precursors were removed by GAC at the beginning of a test run when the influent concentration was high (120 μg/L) with no removals at exhaustion after 30 days of use. Other runs did not experience initial removals as high but were exhausted in about the same time period. The variable influent concentrations were attributed to seasonal temperature changes.

With an average TOC influent concentration of 2–3 mg/L, both the virgin and regenerated GAC showed an initial average removal of about 75%. Upon exhaustion, around 60 days, the removal was 23%.

Because the virgin and subsequent regenerated GAC performed similarly for all runs, an average loading curve and carbon use rate for TOC was constructed as shown in Figures 15 and 16. The average loading on the GAC at the point of exhaustion (60 days) was about 20 mg TOC/g GAC. In comparison, the carbon use rate for TOC at exhaustion was about 47.9 mg/L (0.4 lbs/1,000 gallons).

If, however, 30 days were used for GAC exhaustion as indicated by the InstTHM, then the average loading for TOC would be less (13 mg TOC/g GAC) and consequently the carbon use rate would be higher at 95.8 mg/L (0.8 lb/1,000 gallons) indicating less efficient GAC adsorption for TOC.

Chlorine dioxide as a disinfectant in this study did not produce any organic byproducts other than those noted with chlorine disinfection when looking at the priority pollutants. Chlorine dioxide is an effective disinfectant and its use can control the production of THM, but its widespread adoption has not been advocated until health effect studies have been completed. On the other hand, its use should not be completely abandoned before these studies have been completed.

The principal author did an extensive literature survey during this project but most references are not included in the text because only the results of the field study are presented. However, information gathered

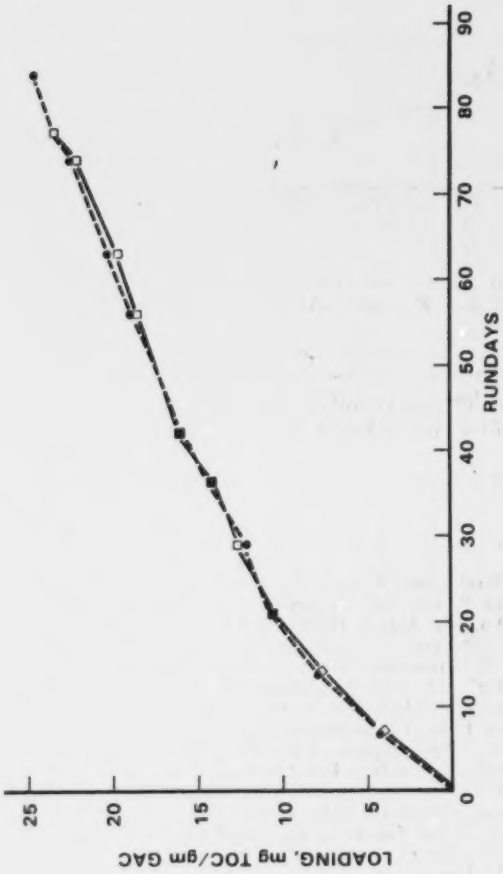

Figure 15. Comparison of average loading curve for TOC for virgin and regenerated GAC. Key: ●, virgin GAC and □, regenerated GAC.

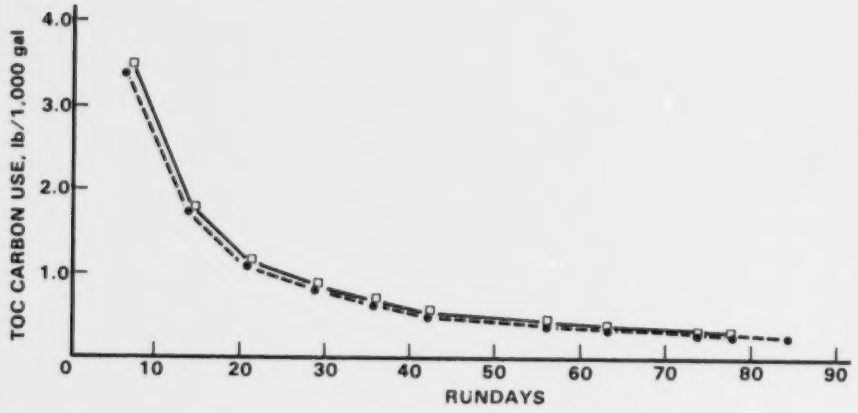

Figure 16. Comparison of carbon use rate for TOC for virgin and regenerated GAC. Key: ●, virgin GAC; and □, regenerated GAC.

from the literature on the use of chlorine dioxide disinfection was evaluated during the project and considered in presentation of the results. This applicable literature is listed (*4–26*).

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